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A SEARCH FOR PRE- AND POST-BURST EMISSION FROM WELL-LOCALIZED GAMMA-RAY BURST LOCATIONS

A. Gordon Emslie, Principal Investigator

Semi-Annual Report

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The results to date of this work are summarized conveniently in the attached reprint, written by graduate student John Horack and myself, and which appeared in a recent issue of *The Astrophysical Journal.*

Work continues on constraining gamma-ray burst models in light of these results and in view of the growing consensus in the community that gamma-ray bursts may well be situated at cosmological distances. Mr. Horack has successfully defended his Ph.D. dissertation and has returned to work at NASA/MSFC; consequently we are currently seeking a new graduate student (or post-doctoral research associate) to assist us in this effort.

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A SEARCH FOR NONBURST EMISSION FROM THE POSITIONS OF WELL-LOCALIZED GAMMA-RAY BURSTS

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ABSTRACT

In this paper, we present the results from the first long-term search for nonburst gamma-ray emission from the positions of 70 intense, well-localized bursts. Using the BATSE occultation technique, designed for monitoring of discrete sources, these burst positions were measured in the energy range of ~ 15 keV–1.8 MeV over a 112 day interval during 1991. None of these 70 locations exhibited detectable emission at or above the level of $\sim 5 \times 10^{-9}$ ergs cm^{-2} s^{-1} during the 112 day interval. This level is approximately 1000 times less than the typical intensity of the burst associated with the given location. In addition, 35 intense gamma-ray bursts detected by BATSE were examined in a 5 day interval centered on the time of detection. We find no compelling evidence that these bursts emit preburst emission or display prompt postburst emission at a level of $\sim 5 \times 10^{-9}$ ergs cm^{-2} s^{-1} on timescales of ~ 1 hr or longer. The lack of detectable long-term emission or pre- and postburst emission from the positions of gamma-ray bursts has important consequences for a variety of burst production models.

Subject headings: gamma rays: bursts — gamma rays: observations

1. INTRODUCTION

The data from the Burst and Transient Source Experiment (BATSE) on the *Compton Gamma Ray Observatory* (*GRO*) have shown that gamma-ray bursts possess an angular distribution that is consistent with isotropy, yet the bursts are spatially inhomogeneous (Meegan et al. 1992a, b; Fishman et al. 1993). These two features make the bursts unlike any other known distribution of galactic objects. Statistical uncertainties generated because of the finite sampling of the parent distribution (Horack et al. 1993; Briggs et al. 1993) scale as $1/\sqrt{N}$, where N is the total number of bursts in the sample. Consequently, if any anisotropy is present at a very low level in the angular distribution, it will take an extremely large number of bursts before this anisotropy can be discovered.

We believe that is not likely that the detection of more bursts will produce an anisotropy that indicates the true distribution, and therefore indirectly the distances, of gamma-ray bursts. It is worthwhile, then, to examine additional features of the burst data in an attempt to solve the mystery of these objects. The positive detection of a counterpart object to the gamma-ray burst, or identification of quiescent emission at some wavelength from the burst source are two areas in which may be found substantial clues yielding insight into the nature of the bursts.

The BATSE experiment has a primary scientific objective of detection and localization of gamma-ray burst events. In addition to this objective, however, there are several secondary scientific objectives. Among these are the monitoring of the entire sky for transient events and measurement of the intensities of known discrete gamma-ray sources. These analyses are performed by using the Earth as an occulting disk to measure the intensities of these sources as they rise or set over the horizon. The technique is described in detail elsewhere (Harmon et al. 1991) and was used, for example, in the discovery and analysis of the transient source GRO J0422+32 (Paciesas et al. 1992).

In this work, we present the results of the application of this technique to systematically search the BATSE database for long-lived or transient nonburst emission from positions of intense gamma-ray bursts. Analysis of the emission produced at times other than the time of the gamma-ray burst itself could yield insight into the temperature, composition, magnetic field, and distance associated with the gamma-ray burst production site. The frequency of such pre- and postburst emission produces significant constraints on the various models of burst production.

Detection of only one confirmed episode of discrete emission from the site of a gamma-ray burst, either before or after the burst event, would contribute significantly to the current amount of knowledge regarding the burst environment. For example, confirmed blackbody emission would immediately yield a measurement of the distance to the burst source. The observed energy flux F of a blackbody is well-known

$$F_{\rm obs} = \frac{A\sigma T^4}{4\pi r^2}, \tag{1}$$

where A is the emitting area, and r is the distance to the source. The emitting area, although not known, can be given an upper limit through analysis of temporal fluctuations in the burst profile. Fitting the observed spectrum to that of a blackbody yields the appropriate temperature T, and the flux F is measured from the detected radiation. If the distance to a source could be found, it would arguably be the single most important piece of evidence to date in the study of gamma-ray bursts and would immediately eliminate whole classes of burst production models.

With approximately 15 orbits per day, BATSE has the capability to make ~ 30 daily measurements of any position on the sky that is occulted by the Earth. Emission prior to the burst is as easily detectable as emission after the burst, once the location of the event is known. No other instrument offers the capability to frequently measure emission from the positions of

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strong gamma-ray bursts over a period of time exceeding 2 yr in the only region of the electromagnetic spectrum in which gamma-ray bursts are known to emit energy. This marks the first time, therefore, that such an extensive time history of the emission from the sites of gamma-ray bursts has been generated over such a long duration.

2. METHOD OF ANALYSIS

2.1. *The Bursts and Times Used in the Search*

We have obtained the locations of 35 extremely intense BATSE gamma-ray bursts. Each of these bursts has an intensity defined by $C/C_{min} > 20$, where C is the maximum counting rate during the burst, and C_{min} is the threshold counting rate at the time of detection. The ratio of these two numbers provides a measure of the burst intensity above the background level. A burst with $C/C_{min} = 1$, for example, is exactly at the threshold of detection. Many of these bursts have also been detected by the Interplanetary Network (IPN) of spacecraft (Cline et al. 1992), and therefore have very precise localizations. Because these bursts are very intense, they are, on average, closer than the weaker gamma-ray bursts. Therefore if nonburst emission exists at some level, the probability of detection is higher from these bursts due to their relative proximity.

We have also obtained the locations of 35 gamma-ray bursts from the Atteia et al. (1987) catalog which have well-defined interplanetary network location error boxes, not simply an annulus or other large region of the sky. These bursts were all detected prior to February of 1980, by instrumentation with more limited sensitivity than BATSE. Each of these 35 events were localized by the IPN, and therefore are bursts with large intensities. The inclusion of these bursts into this work offers the added feature of studying the possibility of emission several years after the actual burst itself. A complete list of the bursts and their locations is provided in Table 1. Those bursts detected by BATSE are listed on the left-hand side of the table and are indicated by their 1B catalog number (Fishman et al. 1993). (Bursts not in the BATSE 1B catalog are identified by a superscript "a" and their date of detection.) Those bursts from the Atteia et al. (1987) catalog are listed on the right-hand side of the table, and are designated by their date of detection.

In addition to the 70 gamma-ray bursts listed in Table 1, two locations of blank sky at $(\alpha, \delta) = (14^h9^m, -38\overset{\circ}{.}2)$ and $(\alpha, \delta) = (4^h46^m, 17\overset{\circ}{.}4)$ were also examined in the search and serve as control samples for the detection of emission.

The search for nonburst emission was performed in two parts. The first part involved the examination of 10 consecutive spacecraft pointing periods spanning a time from Truncated Julian Date (TJD) 8392 to TJD 8504. This portion of the mission was chosen because of the availability of the spacecraft tape recorders. During this interval, both of the tape recorders on *GRO* were working normally. This provided nearly uninterrupted data coverage in any given 24 hr period of time. Consequently, almost all of the burst occultations can be measured. Later in the mission, after the tape recorders had failed, data coverage was substantially degraded. Choosing one of these time intervals would have severely limited the number of measurements that could be made on the burst locations.

During this 112 day interval, each of the 70 gamma-ray burst locations and the two control samples were measured using the BATSE occultation technique at each rise and set of the source location as the spacecraft orbited the Earth. The measurements were then examined to determine the absence or presence of detectable emission. These one-orbit measurements were also combined into a total-day measurement to improve the sensitivity. Table 2 lists the specifics of each pointing period used. The beginning and end of each pointing period is listed by TJD and seconds of day. The column labeled BATSE GRBs indicates the bursts from Table 1 that were detected in each of the 10 pointing periods used.

The second part of the search involved only those gamma-ray bursts detected by BATSE. A 5 day period centered on the time of the detection of each gamma-ray burst was measured for the presence of immediate pre- or postburst emission. For seven of the bursts, this measurement was performed in the first

TABLE 1

GRBs Used in the Search for Nonburst Emission

Burst	α	δ	Burst	α	δ
910421	269.3	26.5	780921a	132.6	34.4
910430	135.3	−0.2	781006b	2.1	13.4
910503	87.2	37.6	781104b	301.5	−21.6
910522	137.9	−51.8	781115a	210.8	52.2
910601	311.4	33.7	781119	19.2	−28.9
910609	108.9	−41.7	781121a	255.8	0.6
910627	200.0	−3.2	781124	181.3	23.9
910717	250.3	−59.8	790101	183.0	15.0
910807	154.2	6.1	790107	271.0	−24.0
910814	352.1	32.3	790113	247.5	−76.5
911104	213.1	35.8	790211	142.7	7.4
911106	345.2	−37.2	790307	209.9	−46.8
911109	111.4	−26.3	790313	93.7	−46.1
911118	165.0	−15.6	790325b	272.5	31.4
911126	158.7	5.7	790329	157.0	45.9
911127	270.8	49.8	790331	291.4	3.6
911202	173.0	−24.7	790402b	122.6	−50.4
911209	262.8	−45.7	790406	347.8	−49.9
920311[a]	131.6	−36.1	790412b	93.2	−5.2
920315[a]	322.2	−23.1	790418	88.0	−7.0
920325[a]	352.7	11.6	790419	334.7	−42.0
920406[a]	289.0	−57.6	790504	347.8	31.9
920414[a]	87.0	−77.9	790514	37.7	60.7
920501[a]	123.8	−32.7	790613	213.1	78.9
920513[a]	216.0	−45.8	790622	325.6	−41.4
920517[a]	202.7	−18.0	790731	101.3	22.5
920525[a]	303.2	−42.4	791014	96.3	−34.6
920627[a]	169.2	−0.3	791031a	254.9	−82.3
920711[a]	281.9	73.0	791101	294.6	38.1
920718[a]	292.3	−54.7	791105a	251.2	24.3
920720[a]	202.9	36.7	791105b	342.9	−2.5
920902[a]	280.3	−21.3	791109	132.0	−35.0
921022[a]	253.6	−11.8	791116	2.6	−16.0
921123[a]	328.8	−54.3	791215	51.5	51.5
930131[a]	182.2	−9.8	800105	13.1	7.6

[a] Bursts detected after 920305 are not contained in the BATSE 1B catalog (Fishman et al. 1993).

TABLE 2

Time Periods Used in the 112 Day Search

Target	Begin	End	BATSE GRBs
Crab	8392/61400	8406/67860	1B 910522
Cyg X-1	8406/70900	8415/700	1B 910601
Sun	8415/4000	8422/67000	1B 910609
SN 1991T	8422/70000	8435/70000	1B 910627
NGC 4151	8435/72000	8449/64000	None
Gal Ctr 0–4	8449/67000	8463/70000	1B 910717
SN 1987A	8463/72500	8476/56000	1B 910807
Cyg X-3	8476/60000	8483/62500	1B 910814
G. Plane 25	8483/64600	8490/50500	None
Vela PSR	8490/53000	8504/51000	None

part of the search because these bursts were detected during the 112 day interval.

These two modes of searching are somewhat complementary. The first mode allows for the assessment of long-term emission from each of the sources, while the second mode allows for the investigation of burst-related emission that may occur just prior to or after the burst itself.

2.2. *Mechanics of the Search*

The BATSE occultation software package was modified for this study so that the 70 burst locations and two control sample locations could be measured in a stand-alone batch mode, without interfering with the daily mission operations tasks. The BATSE CONTINUOUS (CONT) data type (see Horack 1991 for a complete description) from the Large Area Detectors was used to provide 14 energy channel coverage over the range of approximately 15 keV–1.8 MeV. The highest and lowest energy channels were not used to avoid possible instrumental effects. Each of these 14 energy channels is measured individually at each occultation edge. Individual channels could then be combined over a wide variety of ranges and combinations to improve sensitivity to various spectral shapes.

The measurements were performed in a similar manner for both the first and second part of the investigation; the long-term emission search and burst related search, respectively. Each source location was assigned a source-history file for a given pointing period or 5 day interval near the burst. As the software performed the measurements of the occultation edges in the time period under consideration, the results from each location were stored into their respective source-history files. When occultation measurements in the time interval were complete, each of the source-history files contained the results of flux measurements from typically 200–300 transits of the source location across the Earth's limb. Each of these flux measurements were then examined to determine if a significant detection had been recorded.

A large software package was developed to examine the source-history files. A summary program was used first to identify all individual channel measurements that were given a significance of 3 σ or higher by the occultation software. This program also identified the presence of any two or more adjacent energy channels in a given occultation edge that displayed a 2 σ or higher significance. False detections that were not flagged by the occultation analysis program, such as interfering known discrete sources (e.g., Crab, Vela, Cyg X-1), poor quality data, etc., were easily identified using this summary program.

Interesting occultation edges were then examined further with additional software and visually. To further analyze these edges, programs were written to generate spectra, create three-dimensional (intensity vs. time and energy channel) surface plots and contour plots of the occultation history, and perform linear least-squares fits to the flux measurements. These programs are capable of operating on the individual flux measurements contained in the source history file, or could be used on combinations of user-selected channels and times to increase sensitivity. This standard analysis was performed for all 72 of the locations in a given pointing period and for the 35 BATSE-detected bursts in the 5 day interval centered on the time of detection. In total, over 240,000 occultation measurements were made and analyzed at some level depending on the results of the measurement.

The sensitivity of BATSE to nonburst emission using the occultation technique is dependent on a number of parameters. The primary factor in determining the sensitivity is the spacecraft orientation with respect to the source location. As the orientation of the spacecraft changes with respect to a given location on the sky, the projected areas of the detectors observing the position change, and the number of detectors with significant projected areas can also change. A secondary contributor to the sensitivity is the angle β, the angle between the source and the orbital plane of the satellite. Sources near the poles of the orbit are not occulted by the Earth, and consequently cannot be detected using the occultation technique. Sources that lie near the orbital plane have the most rapid transition through the atmosphere limb, producing the sharpest occultation edges that are more easily identified. The sensitivity is also energy dependent. The estimated BATSE 3 σ sensitivity, approximately 0.15 Crab, is shown in Figure 1.

3. RESULTS OF THE SEARCH FOR EMISSION

3.1. *General Result: No Detection*

The gamma-ray burst locations are extremely quiet. Despite the analysis of 70 well-known burst locations for a consecutive 112 day period, with nearly 30 measurements possible per day, not one instance of confirmed emission was found. Each of the possible interesting occultation edges (of which, one finds an average of approximately six per pointing period) obtained in the search could be explained by an interfering source in a nearby region of the sky, sunrise after a flare, an electron precipitation event, the flickering of sources such as Cyg X-1, or other phenomenon not connected with the burst location under analysis. Combining the individual occultation measurements into a set of daily measurements to improve the sensitivity failed to yield any detectable emission. During the entire 112 day period, no two consecutive occultation edges from any of the 70 burst locations displayed evidence of emission in any CONT channel at a significance level of 3 σ or greater, as determined by the occultation software. There is no detectable emission on timescales of hours from any of the 70 locations of the intense gamma-ray bursts at a level of $\sim$0.15 Crab for the 112 day period that was examined.

Table 3 contains the average number of CONT energy channels per occultation edge with a significance of 3 σ or more in

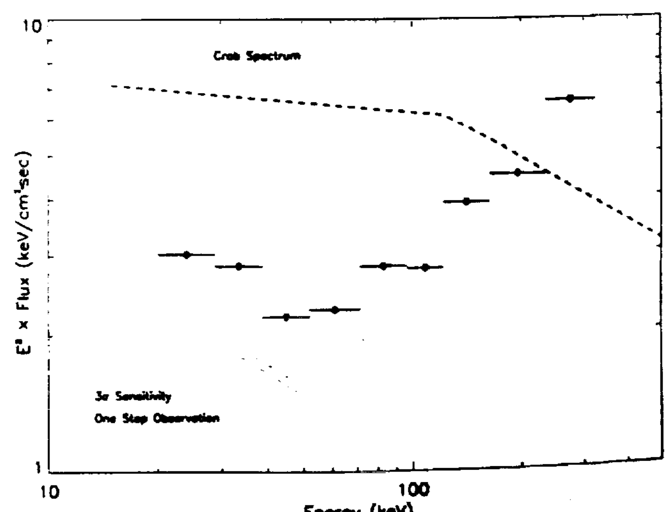

FIG. 1.—The estimated one-step occultation sensitivity of BATSE as a function of energy.

TABLE 3

AVERAGE NUMBER OF CHANNELS PER OCCULTATION EDGE WITH A MEASURED SIGNIFICANCE 3 σ

Sample	Value
BATSE:	0.074 ± 0.012
Atteia:	0.072 ± 0.009
Blank:	0.06 ± 0.02

the measured flux, as determined by the occultation software for the BATSE locations, the Atteia locations, and the control samples. It is important to note that the occultation software can measure a decrease in the intensity when a source is supposed to rise above the horizon, and vice versa. These are reported as negative measurements (e.g., $-3\ \sigma$) by the software, where the minus sign indicates that the measured edge is in the wrong direction.

The agreement between the three sets of locations is obvious. In approximately 100 occultation measurements of a burst location, one expects approximately seven of the energy channels to display a fluctuation that is 3 σ or greater in one direction (source rise) or the other (source set). By examination of the numbers in Table 3, the BATSE and Atteia burst locations are indistinguishable. More importantly, these locations are consistent with the number of fluctuations expected from a location that is not associated with any burst. No individual location from either the BATSE or Atteia set of bursts was found to be clearly inconsistent with the measurements obtained from regions of blank sky.

As the second part of the investigation into nonburst emission, we examined 5 days of data centered on the time of each of the 35 BATSE burst detections. Figure 2 shows the typical result obtained from the search; no significant emission at the level of ~0.15 Crab is identified for approximately 2.5 days prior to or after the burst. The source of gamma-ray bursts appear to be rather quiet unless, of course, they are bursting. This particular figure is from a measurement of 1B 910522, BATSE trigger number 219 (Fishman et al. 1993), in CONT channel 11, where one would expect to find any 511 keV emission that is present, but the result is typical. Combining energy channels to search for broad-band emission and combining occultation steps to improve sensitivity yielded no statistically significant detections of emission in the short periods of time sampled.

3.2. *The Exception to the Rule*

One occultation edge from GB 920711 (BATSE trigger no. 1695) showed an apparent significant flux. This burst was a very intense, complex event lasting over 100 s. The time profile, shown in the energy range of 50–300 keV in Figure 3, displays an extensive amount of structure, with statistically significant fluctuations on the order of ~100 ms. This burst was detected by BATSE on TJD 8814 at 58140.573 UT. The location of this event was obtained from the Third Interplanetary Network, and the occultation times for this location were computed over a 5 day period centered on the time of detection by BATSE. The location of this event and the orientation of the sky combined to produce a less-than-favorable geometry for detection in many detectors. BATSE detector B7 was the most brightly illuminated detector, with detector B3 having a smaller yet still significant projected area to the burst's location.

The occultation edge that displayed a possible source detection was a rise of the location above the horizon at 7,510.61 s of TJD 8814. This particular rise was ~50,000 s before the burst was detected by BATSE. Figure 4 contains a plot of this occultation edge as seen by detector B7 in CONT channels 1–7. The corresponding energy range is approximately 20–150 keV. At approximately 7,510 s, the time of the predicted rise, the data from this detector show a clear occultation-like feature. The dotted lines to the left and right of Figure 4 indicate the computed background levels in the regions before and after the rise of the location above the horizon. The other seven BATSE detectors were examined at this time as well. Detectors B0, B1, B2, B4, B5, and B6 all showed no evidence of an occultation step. Detector B3, the detector with the second-largest projected area to the source, showed a hint of an occultation step. The lack of an occultation step in the other

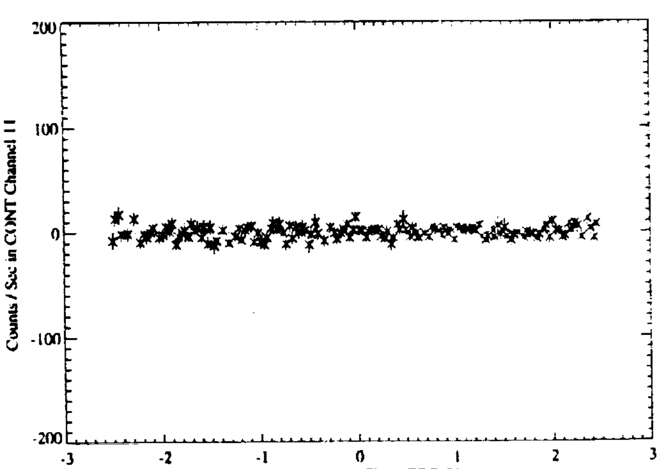

FIG. 2.—Occultation edge history for 1B 910522 (BATSE Burst no. 219) in BATSE CONT channel 11, an energy range of approximately 430–600 keV.

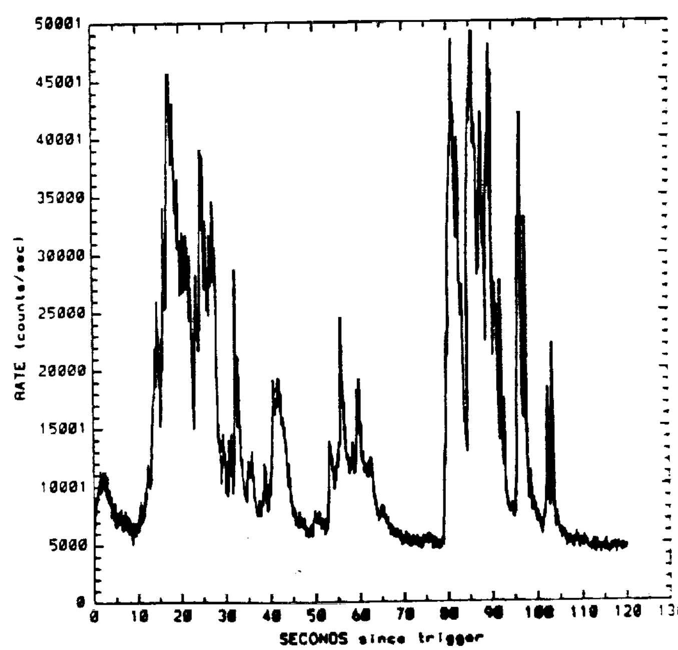

FIG. 3.—Time history of GB 920711 in the range 50–300 keV.

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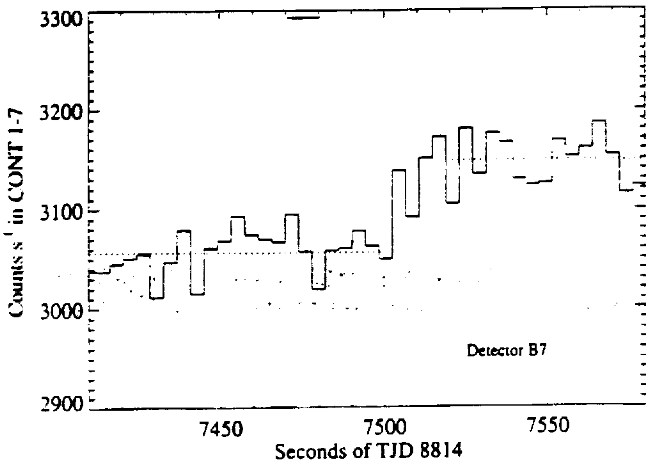

FIG. 4.—Occultation edge from GB 920711 showing a possible detection.

detectors, with the possible exception of B3, is in agreement with the orientation of the satellite with respect to the source at the time of detection. The BATSE occultation software computed an intensity of 134.9 ± 25.0 counts s^{-1} over this channel range.

Figure 5 displays a count-spectrum of this occultation step as measured by the BATSE software. The intensity in counts cm^{-2} s^{-1} keV^{-1} is plotted as a function energy. A positive detection is registered in each of the energy bins up to an energy of ~ 120 keV. No other occultation edge measured in the entire study displayed this type of consistent positive detection over a large range of consecutive energy channels.

The feature in Figure 4 is consistent with an occultation step from the location of GB 920711. It occurs at the proper time, in the proper detectors, and has the correct sense (i.e., it is an increase in the counting rate at the time of the source rise). If this particular detection is real, Figure 5 indicates the peak flux of the detected emission is near 50 keV, and falls below the BATSE sensitivity at approximately 150 keV. We find that this feature cannot be plausibly explained by an interfering source, SAA feature, electron precipitation event, or other phenomenon. Alternatively, the occultation edge is consistent with the rise of a source somewhere else at the Earth limb at the time of detection. In a classic example of Murphy's law in action, this particular edge is the last available measurement prior to the burst due to poor data quality resulting from the malfunction of the spacecraft tape recorders. We therefore have no way to determine if the feature is present in any of the subsequent occultation edges prior to the detection of the burst $\sim 50{,}000$ s later. In light of the tremendous number of edges measured from the other gamma-ray bursts, and in light of the fact that the analysis yielded a great null result, we feel that we cannot claim this particular edge as evidence of nonburst emission from an identified burst location. If the progenitor objects of gamma-ray bursts produced emission on a regular basis prior to the actual burst itself, additional interesting occultation edges similar to this one should have been found.

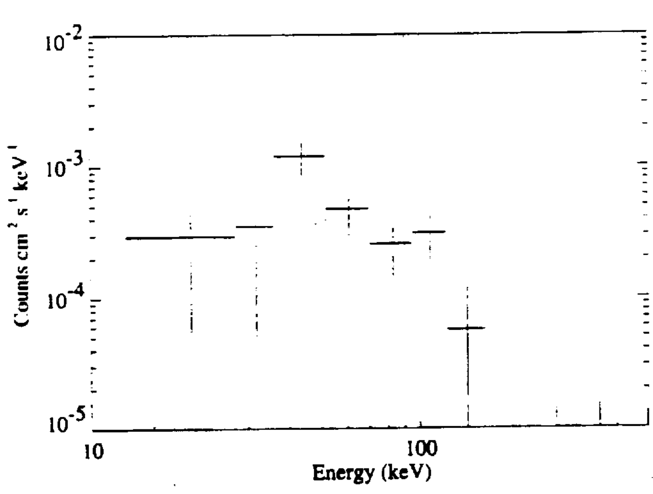

FIG. 5.—A BATSE count spectrum of the GB 920711 occultation edge.

4. IMPLICATIONS FOR CURRENT BURST MODELS

A gamma-ray burst represents the release of a large amount of stored potential energy. It is unlikely that the mechanism by which this energy is stored is 100% efficient, and it is plausible that some leakage should be detectable prior to the burst. The environment surrounding a gamma-ray burst is undoubtedly hot, and most likely suffers rather profound excitation (if not destruction) as a consequence of the burst. It is not unreasonable, then, to expect that heated, chaotic environments such as these may emit radiation that may be detectable by BATSE. However, we find that such emission either is not present, or lies below the level of our sensitivity to detect it.

The absence of detected emission from the locations of the gamma-ray bursts, combined with the known sensitivity limit of BATSE, can be used to place an upper limit on the amount of emission that can possibly be present. We have presented the estimated one-step sensitivity for the occultation technique in Figure 1. Taking an average value of 3 keV cm^{-2} s^{-1} over the energy range displayed in the figure, one obtains an upper limit of $\sim 5 \times 10^{-9}$ ergs cm^{-2} s^{-1}.

We contrast this with the intensity of the bursts in the sample. The average peak flux for the bursts in the sample is approximately 10 photons cm^{-2} s^{-1} in the energy range 50–300 keV (see Fishman et al. 1993). With an average photon energy of ~ 200 keV, one has an average peak flux of approximately 3×10^{-6} ergs cm^{-2} s^{-1}. This is nearly three orders of magnitude larger than the upper limit obtained in the previous paragraph. The level of quiescent emission that is allowed from the burst progenitor objects is therefore approximately a factor of 1000 below the level of the emission during the burst.

The *CGRO* has an orbital period of ~ 90 minutes. Consequently, each source is measured once every 45 minutes on average. It is therefore possible that the progenitor objects of bursts emit radiation at or above the level of 5×10^{-9} ergs cm^{-2} s^{-1} for timescales of minutes or seconds, and that these short-term emissions may go largely unnoticed due to the comparatively low duty cycle of measurement on a given source. Longer emission episodes may also occur; however, their occurrence must be very infrequent to have escaped the detection of this study.

These limits have important consequences for a variety of gamma-ray burst models. Many gamma-ray burst models published both before and after the announcement of the BATSE results involve the accretion of material onto a compact object. Dar et al. (1992), for example, have proposed that accretion of material onto white dwarf stars in binary systems produce a gamma-ray burst when the mass of the white dwarf crosses the Chandrasekhar limit, causing the core of the white dwarf to collapse into a neutron star. Other models involving accretion onto a compact object have been hypothesized by Woosley et al. (1992), Frank et al. (1992), Blaes et al. (1990), and Melia (1988). Numerous X-ray binaries are observed in the X-ray and gamma-ray region of the spectrum through radiation generated as material is accreted onto their surfaces. Van Paradijs (1992) has noted that if gamma-ray bursts are produced in systems with accretion, and since accretion is known to be a process in which X-ray and gamma-ray emission is generated, then these burst progenitor objects must, at some level, be a source of emission caused by accretion. We assert that this level of emission must be at least three orders of magnitude less than the intensity of the gamma-ray burst itself.

The absence of emission near the time of the burst also has important consequences for burst production models. It is clear from these results that the progenitor objects of bursts show no detectable increase in their energy output or offer any indication through emission that a burst is imminent. There is no detectable emission after the burst either. These may imply that the bursts occur in an extremely clean environment.

Meszaros & Rees (1992) have proposed the production of gamma-ray bursts from the mergers of binary systems containing two neutron stars or a neutron star and a black hole. In the merger, tidal heating of the objects produces a burst of neutrinos with energy on the order of 10^{53} ergs. Annihilation of $\nu\bar{\nu}$ pairs then produce the high-energy photons detected as a gamma-ray burst. As the binary system decays, one may envision a number of mechanisms for the emission of X-ray or gamma-ray radiation shortly before the burst from smaller episodes of tidal heating, from heating of material in the region of the objects, acceleration of charged particles by the magnetic field of the neutron star, etc. It is apparent that if such emission exists, it is below the level of detection.

Fencl et al. (1992) have discussed the possibility of 511 keV "afterglows" from gamma-ray bursts due to the presence of unstable ^{15}O and other radioactive nuclei created by direct photoerosion, as well as electron-positron annihilation in the region of the burst. The timescales estimated by Fencl et al. for detection of significant emission after the burst are typically on the order of minutes because of the relatively short half-lives of the generated isotopes. This timescale is somewhat shorter than the capability of this search. If such photoerosion occurs, and the signal is detectable, it must be gone within ~ 45 minutes after the burst. Future investigations should attempt to shorten the timescale of measurement either by concentrating on bursts that occur near their orbital set below the horizon, or through alternative measurement techniques.

If bursts are associated with neutron stars, the burst radiation must eventually encounter the supernova remnant from the event that created the neutron star. The interaction of the supernova shock wave from SN 1987A has been observed interacting with the surrounding material as a ring of emission in a widely publicized photograph from the *Hubble Space Telescope*. It is also possible that the interaction of the gamma-ray burst photons with the supernova ejecta surrounding the neutron star may produce observable effects. In the context of these models, the lack of such a detection may imply that the neutron stars are extremely old, so that either the supernova ejecta are very diffuse, or the neutron star has moved sufficiently far away from the ejecta that the effect of the burst on the material is minimal.

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